DESCRIPTION

RADIO COMMUNICATION SYSTEM

The present invention relates to a radio communication system, a mobile station and a base station for use in such a system, and to a method of operating such a system.

In a radio communication system comprising base stations of fixed location and mobile stations, transmissions from a base station to a mobile station take place on a downlink channel and transmissions from a mobile station to a base station take place on an uplink channel. It is known for such systems to use transmission format control in which a mobile station measures the quality of a received downlink signal and transmits reports of the quality (typically referred to as Channel Quality Information (CQI) reports) to a base station, and the base station then schedules packet transmissions to certain mobile stations and selects a transmission format, for example modulation and coding scheme, suitable for optimising communication under the prevailing channel conditions. Such CQI reports may provide an indication of, for example, carrier to interference ratio, signal to noise ratio, delay spread, or a recommended transmission format suited to the prevailing channel conditions.

Also, it is known to use closed loop transmit power control in which a mobile station measures the quality of a received downlink signal and transmits transmit power control (TPC) commands to the base station so that an adequate, but not excessive, received signal level is maintained at the mobile station despite fluctuations in downlink channel conditions.

Typically, the quality measurements used for generating the CQI reports are made on a downlink signal whose transmit power is not varied by a closed loop power control process, but the quality measurements used for generating the TPC have to be made on a downlink signal whose transmit power is varied as a result of the TPC commands, in order to achieve closed loop operation.

Furthermore, it is known to use open loop transmit power control in which the base station measures the quality of a received uplink signal, estimates the attenuation occurring on the uplink, and adjusts the downlink transmit power on the assumption that the attenuation on the downlink is similar to the uplink.

There is a requirement to permit interruptions in the power control process, for example, to enable the mobile station to make measurements on other channels in preparation for handover to another system. During such an interruption the open or closed transmit power control loop may be broken. The transmit power control loop is re-established when the uplink transmission (and downlink transmission in the case of closed loop power control) resumes after the interruption.

The CQI reports are generally transmitted at a lower rate than the TPC commands and so the TPC commands can additionally be used by the base station to assist scheduling of transmissions and selection of a transmission format. However, as a result of the interruption in the power control process, the transmit power may temporarily be non-optimal, which may consequently result in packets being scheduled to the mobile stations with a poor channel quality or an unsuitable transmission format being used temporarily. Transmission of data using an unsuitable transmission format may be unreliable if the transmission format is insufficiently robust, or waste resources if the transmission format is unnecessarily robust. Alternatively, transmission of data could be deferred until the power control process resumes and has re-converged. In either case, system capacity may be wasted resulting in inefficiency.

An object of the present invention is to contribute to improved efficiency.

According to a first aspect of the present invention there is provided a mobile station for use in a communication system having a base station, the mobile station comprising power control signal generation means for generating a power control signal for enabling the base station to adjust its transmit power level in accordance with a power control loop process, report

generation means for generating reports from measurements of a characteristic of a signal received from the base station, transmitter means for transmitting the reports and the power control signal to the base station, and transmission control means adapted to control the time of transmission of the reports such that first of the reports are transmitted at a predetermined sequence of times and, in response to an interruption in the power control loop or the reporting, and for a period existing at least one of before, during and after the interruption, one or more second of the reports are transmitted at times not coincident with the predetermined times.

The interruption in the reporting may be an interruption in the report generation, or an interruption in the transmission of the reports, or an interruption in the reception of the reports by the base station which may be detected by the mobile station.

By transmitting CQI reports at non-predetermined times for a period when an interruption occurs, the reporting of the downlink quality to the base station is improved. Reports can be transmitted closer to the interruption than the predetermined times, and additional reports can be transmitted. As a result, the base station can improve its selection of downlink parameters thereby improving packet scheduling and improving the selection of an appropriate transmission format until the power control process is re-established. Subsequent reversion to a lower rate avoids excessive signalling, thereby minimising power consumption and interference.

According to a second aspect of the present invention there is provided a radio communication system comprising a base station and at least one mobile station in accordance with the first aspect of the invention.

According to a third aspect of the present invention there is provided a method of operating a radio communication system having a base station and a mobile station, comprising, at the mobile station, generating a power control signal for enabling the base station to adjust its transmit power in accordance with a power control loop process, transmitting the power control signal to the base station, generating reports from measurements of a characteristic of a signal received from the base station, and transmitting the reports to the base

station, interrupting the power control loop or the reporting and, at the mobile station, controlling the time of transmission of the reports such that first of the reports are transmitted at a predetermined sequence of times and, in response to the interruption, and for a period existing at least one of before, during and after the interruption, second of the reports are transmitted at times not coincident with the predetermined times.

According to a fourth aspect of the invention there is provided a base station for use in a radio communication system, comprising transmitter power control means for, in response to a first signal received from a mobile station, setting the transmit power level of a first transmitted signal in accordance with a power control loop process, control means for selecting, in response to reports received from the mobile station at a predetermined sequence of times, a parameter of a second transmitted signal, and scheduling means for scheduling an interruption in the power control loop process or the reporting, and indicating means for generating for transmission to the mobile station in response to the interruption an indication of one or more further reports to be transmitted for a period at times not coincident with the predetermined times .

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 is a block schematic diagram of a radio communication system;

Figure 2 illustrates diagrammatically options for operation in accordance with the invention; and

Figure 3 is a flow chart illustrating a method of operating a communication system in accordance with the invention.

Referring to Figure 1, there is illustrated a radio communication system 50 comprising a base station 100 and a plurality of mobile stations 200. Transmission from base station 100 to the mobile stations 200 takes place on a downlink channel 160, and transmission from the mobile stations 200 to the base station 100 takes place on an uplink channel 260.

The base station 100 comprises a transmitter means 110 having an output coupled to an antenna means 120 via coupling means 130 which may be, for example, a circulator or changeover switch. The coupling means 130 also couples signals received by the antenna means 120 to an input of a receiver means 140. Coupled to the transmitter means 110 and the receiver means 140 is a control means (µC) 150 for:

generating a control signal for transmission on the downlink, the transmit power of this control signal not being controlled by a power control loop;

setting the transmit power level of a downlink signal, for example a data signal, in response to TPC commands received on the uplink from the mobile station 200;

selecting a transmission format for a downlink signal, for example a data signal, in response to CQI reports received from the mobile station 200; and

scheduling interruptions in the TPC process and generating indications of the occurrence of the interruptions for transmission to the mobile station 200.

Each mobile station 200 comprises a transmitter means 210 having an output coupled to an antenna means 220 via coupling means 230 which may be, for example, a circulator or changeover switch. The coupling means 230 also couples signals received by the antenna means 220 to an input of a receiver means 240. Coupled to the transmitter means 210 and the receiver means 240 is a control means (µC) 250 for:

measuring a downlink signal, for example a data signal, received from the base station and generating TPC commands in accordance with a closed loop power control process;

measuring a characteristic of the received control signal and, from the measurements, generating CQI reports for transmission to the base station 100; and

controlling the time at which the CQI reports are transmitted such that reports are transmitted at a predetermined sequence of times and, in response

to an indication of occurrence of an interruption, one or more report are transmitted at times not coincident with the predetermined times, such reports being referred to for convenience in the present specification as non-predetermined reports.

There are several options for the time at which the period of transmission of non-predetermined reports may start. Also, there are several options for the time at which the period of transmission of non-predetermined reports may terminate. These options are explained in turn below with reference to Figure 2. Figure 2A illustrates the transmission of TPC commands regularly at an interval T_C where no interruption occurs in the power control process. Figure 2B illustrates the transmission of CQI reports regularly at a predetermined sequence of times spaced at an interval T_N where no interruption occurs. Figure 2C illustrates the transmission of TPC commands with an interruption in the power control process which results in a break in the transmission of TPC commands.

Options for starting the period of transmission of non-predetermined reports are as follows:

a) The period may start after the interruption has terminated, as illustrated in Figure 2D where the reduced interval is T_R, and the period commences after a delay T_D from the termination of the interruption.

b) The period may start before the interruption is started as illustrated in Figure 2E, or at the same time as the interruption starts.

c) The period may start during the interruption, as illustrated in Figure 2F.

During the interruption, the transmission of CQI reports may continue as illustrated in Figures 2F, or may be suspended as illustrated in Figures 2D, 2E, depending on, for example, the capability of the mobile station 200 and the purpose of the interruption.

Options for terminating the period of transmission of non-predetermined reports are as follows:

a) Where the period starts before the interruption starts, the period may also terminate before, or at the same time as, the interruption starts, or may terminate during the interruption or after, or at the same time as, the

interruption is terminated. Figure 2E illustrates the period starting before the interruption and ending at the same time as the interruption starts. In this example, the duration of the period is T_{P2} and two additional CQI reports are transmitted at non-predetermined times before the interruption; the transmission of CQI reports is suspended during the interruption, but the additional CQI reports provide additional information to assist the base station.

b) Where the period starts during the interruption, the period may also terminate during, or at the same time as, the interruption (this option is not illustrated in Figure 2) or after the interruption, as illustrated in Figure 2F which shows the duration of the period is T_{P3} and four additional CQI reports are transmitted at non-predetermined times.

c) Where the period starts after the interruption is terminated as illustrated in Figure 2D, or at the same time as the interruption is terminated, the period must of course terminate after the interruption is terminated. In Figure 2D the duration of the period is T_{P1}.

Some examples of options for determining the duration of the period of transmission of non-predetermined reports are as follows:

a) The duration may have a predetermined value.

b) The period may continue until the power control process has resumed after the interruption and the power control loop has converged in accordance with a predetermined criterion. The convergence may be detected by the control means 150 of the base station 100 and signalled to the mobile station. Alternatively, the convergence may be detected by the control means 250 of the mobile station 200. Convergence may be detected, for example, by a reversal of the sign of one or more TPC commands.

Any of the start time, end time and duration of the period of transmission of non-predetermined reports may be dependent on the length of the interruption to the power control loop, for example where the interruption is short, a short period of reduced interval may be used before the interruption, and where the interruption is long, a long period may be used after the interruption.

Any of those CQI reports that are separated, as a result of the non-predetermined reports, from another CQI report by the reduced interval T_R may be generated from a measurement of shorter duration than is used to generate other reports. For example, the maximum measurement duration may be T_R where the interval has the reduced value T_R, whereas those CQI reports spaced at the normal, longer interval T_N may be derived from longer measurements. The measurement may, depending on the capability of the mobile station 200 and the purpose of the interruption, be prevented from starting until the interruption has terminated. So, for example, in Figure 2D the maximum duration of the measurement used to generate the first CQI report transmitted after the end of the interruption may be T_D, or shorter than T_D if some processing time is required between completion of the measurement and the start of transmission of the corresponding report.

If the measurement is started during the interruption, any other measurements during the interruption, such as examination of channels on another system in preparation for handover, may be curtailed in order to allow time for making a measurement from which a CQI report is generated. There may be a trade-off between accuracies of these two types of measurement in order to establish the optimum division of the available time.

Optionally, CQI reports transmitted at non-predetermined times or at different intervals may also be coded differently from the other reports.

In Figures 2D and 2E, where the period of transmission of non-predetermined reports has terminated and the normal, longer interval T_N has resumed with the transmission of CQI reports at only the predetermined times, the timing of the CQI reports is illustrated as being the same as if the interruption had not occurred, as in Figure 2B. However this same timing is not essential and the CQI reports may be displaced by a time shift applied to the predetermined sequence of times for the transmission of subsequent reports, as illustrated in Figure 2F where the time of occurrence of the final two reports shown in the drawing is advanced compared with the initial sequence of predetermined times sown in Figure 2B.

Figure 3 is a flow chart illustrating a method of operating a communication system made in accordance with the invention. The method starts at step 505. At step 510 the mobile station 200 sets (may be in response to an instruction from the base station 100) the current CQI reporting interval to T_N and commences (or continues if already in progress) transmission of the periodic TPC commands at an interval T_C.

At step 515 the mobile station 200 measures a characteristic of the received control signal and generates from the measurement a CQI report.

At step 520 the mobile station 200 transmits the CQI report at a time determined by the current reporting interval T_N, which is in turn determined by the predetermined sequence of times.

At step 525 the mobile station 200 tests whether the power control loop is interrupted, or an interruption is imminent. If the power control loop is not interrupted and no interruption is imminent, flow returns to step 515. If the power control loop is interrupted, or interruption is due before the next CQI report is due to be transmitted, flow proceeds to step 530 where transmission of TPC commands and CQI reports is suspended for the duration of the interruption as illustrated in Figure 2D. Flow proceeds to step 550 when the interruption terminates.

At step 550 the mobile resumes transmission of TPC commands and sets the current CQI reporting interval to a reduced value T_R ($T_R < T_N$), thereby introducing reports at times not concident with the predetermined times.

At step 555 the mobile station measures a characteristic of the received control signal and generates from the measurement a CQI report.

At step 560 the mobile station 200 transmits the CQI report at a time determined by the current reporting interval, now T_R.

At step 565 the mobile station 200 tests whether the period, T_{P1} in Figure 2D, for which the CQI reporting interval is reduced has expired. If this period has not expired flow returns to step 555. If this period has expired flow returns to step 510 where the current CQI reporting interval is reset to the longer value T_N, thereby restoring transmission of reports at the predetermined times.

Throughout the process described above with reference to Figure 3, the base station 100, in response to receiving the CQI reports, may adapt a parameter of a downlink transmission to suit the prevailing conditions.

Optionally, the base station 100 may detect the transmission of the non-predetermined reports at times not coincident with the predetermined times by monitoring the intervals between CQI reports.

Optionally, the mobile station 200 may signal to the base station 100 a change in the interval between, or times of transmission of, the CQI reports to assist the base station 100 receiving the CQI reports.

Optionally, the base station 100, in response to an interruption to the power control loop, may signal to the mobile station 200 an indication of a change in the interval between the CQI reports or of non-predetermined reports to be transmitted by the mobile station 200.

Optionally, only one non-predetermined CQI report may be transmitted before the transmission of reports at the sequence of predetermined times is restored.

The embodiments described above use a closed loop power control process. However, an open loop power control process can be used instead. In this case the mobile station does not transmit TPC commands, but instead transmits a signal on which the base station can make measurements and estimate a suitable downlink transmit power.

The interruption to the power control loop may be for a variety of reasons. For example, in the case of a closed loop power control process, the mobile station 200 may not be able to transmit TPC commands temporarily, as illustrated in Figure 2C, or may not be able to receive the downlink signal temporarily from which it generates the TPC commands, so is unable to transmit effective TPC commands. In the case of an open loop power control process, the mobile station 200 may not be able to transmit an uplink signal temporarily, so the base station 100 may not be able to select an appropriate downlink transmit power level.

Instead of the power control loop being interrupted, the interruption may be to the CQI reporting process. For example, there may be a requirement to

interrupt the transmission of CQI reports while the mobile station transmits another signal. The motivation for such a requirement may be, for example, the making available of sufficient transmission power for the other signal to be transmitted successfully, or the avoidance of large peak-to-average power ratios in the transmitted signal of the mobile station, or the reduction of interference to the other transmission. As another example, the transmission of CQI reports may be interrupted while the mobile station is unable to make the corresponding measurements, or the reception of CQI reports may be interrupted while the base station is unable to receive them. As a further example, the interruption to reporting may occur when one or more uplink or downlink transmission parameters are reconfigured. When interruptions to the CQI reporting occurs, according to the present invention one or more CQI reports are transmitted at non-predetermined times after the interruption. As a result, the base station can improve its selection of downlink parameters. The options described with respect to the invention are available whether the interruption occurs to the power control process or to the CQI reporting.

In the embodiments described with reference to Figure 2, the duration of the reduce interval T_R is the same for each of the CQI reports transmitted with a reduced interval. However, each reduced interval need not have an identical duration.

The functionality of the base station 100 may be distributed across a variety of fixed parts of a communications network. In this specification, the use of the term ``base station" is therefore to be understood to include those parts of a communication network involved in an embodiment of the present invention.

In the present specification and claims the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. Further, the word "comprising" does not exclude the presence of other elements or steps than those listed.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the design, manufacture and use of

communication systems and component parts thereof, and which may be used instead of or in addition to features already described herein.